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INDEX TESTING OF FRACTURES IN URL DIAMOND DRILL CORES (LEVEL II CONCEPT ASSESSMENT DRAFT REPORT)

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INDEX TESTING OF FRACTURES IN URL DIAMOND DRILL CORES
(Level II Concept Assessment Draft Report)

by

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ABSTRACT

Fractures generally control ground water flow through rock masses. They, therefore, provide potential pathways for radionuclide transport from an underground nuclear waste disposal vault contained within a rock formation to the biosphere. Fractures will also influence the long term stability of the mined structure which constitutes the immediate vault area. In regard to the latter, quantitative fracture/joint properties and joint models are required if structural modelling of vault configurations are to be used to assess their stability and integrity for the containment of higher level nuclear waste.

A method of quantitatively describing joint behaviour based on field data and simple index testing is being studied within the Canadian Nuclear Fuel Waste Management Program (NFWMP) to permit the incorporation of such discontinuities in structural model studies. This report describes the procedure used to characterize small scale core samples from the URL lease area in the Lac du Bonnet batholith, Manitoba.

Key words: joint, fracture, hydrogeologic characterization, joint model, nuclear waster disposal, underground research laboratory, shear strength.

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VÉRIFICATION DE L'INDICE DE CASSURES DANS LES ÉCHANTILLONS DE CAROTTAGE AU DIAMANT

(Projet de rapport sur l'évaluation des concepts - Étape II)

par

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RÉSUMÉ

Les cassures contrôlent habituellement l'écoulement de l'eau phréatique dans les masses rocheuses. Par conséquent, elles constituent des voies que les radionucléides d'une fosse souterraine pour déchets radioactifs, située à l'intérieur d'une masse rocheuse, peuvent emprunter dans leur cheminement vers la biosphère. Les cassures influencent également la stabilité à long terme de l'ancienne mine située dans les environs immédiats de la fosse pour déchets radioactifs. Cette dernière devra faire l'objet d'études; des analyses quantitatives des cassures et des propriétés des diaclases, et des modèles des diaclases seront nécessaires afin que le modèle structural des configurations de la fosse puisse servir à évaluer sa stabilité et son intégrité de sorte qu'elle puisse être utilisée pour le confinement de déchets radioactifs plus puissants.

À l'heure actuelle, une méthode utilisée pour obtenir une description quantitative du comportement des diaclases à partir des données obtenues sur le terrain et d'une simple vérification de l'indice, fait l'objet d'une étude dans le cadre du Programme canadien de gestion des déchets radioactifs et des combustibles résiduaires. Cette étude vise à faciliter l'incorporation de ces discontinuités dans les études du modèle structural. Une description de la façon de procéder pour caractériser les petits échantillons de carottage provenant de la région du batholith du Lac du Bonnet au Manitoba est également présentée dans ce rapport.

Mots-clé : diaclase, cassure, caractérisation hydrogéologique, modèle de diaclase, élimination des déchets radioactifs, Laboratoire souterrain de recherche, résistance au cisaillement.

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INTRODUCTION

A principal objective of the Canadian Nuclear Fuel Waste Management Program (NFWMP) is the safe management of nuclear wastes so that there will be no adverse effects on man, or the environment at any time (Simmons et al., 1985). To achieve this objective, Atomic Energy of Canada Limited (AECL) is conducting geomechanics characterization programs at research areas in plutonic rock formations in the Canadian Shield, and developing conceptual designs for disposal vaults. Additionally, an underground research laboratory (URL) is being constructed in the Lac du Bonnet batholith near Pinawa, Manitoba where aspects of the concept of disposing of high level nuclear wastes in plutonic rock will be investigated. As well, underground in situ geotechnical studies and experiments are planned to develop and test methodologies for assessment.

In deep igneous formations, such as the ones being studied under the NFWMP, fractures generally control ground water flow through the rock mass. As a result, fractures could ultimately provide the pathways for radionuclide transport from a repository vault to the biosphere. Fractures will also influence the long term stability of an underground nuclear waste vault. It is important, therefore, to understand fracture behaviour in terms of the expected stress and temperature perturbations which could occur in the rock surrounding a nuclear waste vault. The combined effects of stress and temperature on the hydrogeologic behaviour of fractures must be studied, to permit the development of systematic characterization procedures and to permit their incorporation into mathematical models for predictive purposes.

Documentation of the developed characterization procedures is required for external expert appraisal and to permit utilisation of the developed technology on other generic sites (Dormuth, 1985). To fulfill the above requirements, Concept Assessment Documents (CAD), are currently being prepared under AECL's direction for each of the research areas under study.

Two approaches are being followed by AECL to develop mathematical models and procedures for characterizing rock fractures (Simmons et al., 1985). These are:

(i) a model development based on field data and measurements, and
(ii) a laboratory test program on fractures.

A fracture model development employing field data and measurements, to describe the coupled thermomechanical and hydrological behaviour of rock joints was developed under contract by Barton and Bakhtar, (1983). A methodology was also provided for obtaining the fracture index parameters required for evaluating this model. The methodology has since been used to obtain fracture index parameters on diamond drill cores from the URL lease area, (Jackson et al., 1985), as part of the site screening and site assessment process (Dormuth, 1985). The fracture index parameters required for the Barton and Bakhtar model are:

Joint roughness coefficient (JRC)
Joint wall compressive strength (JCS)
Basic and residual friction angles ($\emptyset_b$ and $\emptyset_r$) and
the type and thickness of fracture infilling material.

The unconfined compression strength (σ_c) of the intact rock material has also been determined as part of this exercise.

As a contribution to the URL concept assessment document currently being prepared for the Lac du Bonnet formation, this report describes the procedure used to characterize small scale core sample fractures from the URL lease area. A range of JRC and JCS values are also provided, which may be used in conjunction with the results of other rock fracture studies, to test the accuracy of mathematical models developed for predicting the coupled thermomechanical and hydrologic behaviour of rock joints.

FRACTURE MODEL DESCRIPTION

Special Features of the Barton-Bandis (1982) Rock Joint Model

The rock joint model provided by Barton and Bakhtar (1983) is an update of the earlier rock fracture model developed by Barton and Bandis (1982). The latter model describes the shear behaviour of rock fractures under

low normal stresses. According to this model, the failure characteristics of a joint system present in a rockmass may be expressed mathematically as follows:

$$\tau = \sigma_n \tan (JRC \log_{10} \frac{JCS}{\sigma_n} + \phi_r) \quad (1)$$

where τ = shear strength of the joint (MPa)

σ_n = normal stress acting across the joint surface (MPa)

JRC = joint roughness coefficient

JCS = joint wall compressive strength

ϕ_r = residual friction angle

An important feature of the above model is that model parameters JRC, JCS and ϕ_r can be easily determined from simple index tests. A comprehensive examination of the Barton-Bandis joint model, and description of the procedures for obtaining its parameters from joint core samples has been provided by Barton and Bakhtar (1983).

Provided below is a condensed description of the procedure used to characterize the small scale fractures in drill core samples from Lac du Bonnet batholith.

DESCRIPTION OF MEASUREMENTS

Rock Joint Characterization Procedure

The characterization of Lac du Bonnet granitic samples containing natural joints involved the following principal steps:

(i) Joint recognition.

(ii) Joint wall compressive strength (JCS) determination.

(iii) Joint roughness coefficient (JRC) determination.

(iv) Estimation of the residual friction angle (ϕ_r).

Joint Recognition

This process involved visual inspection, selection and identification of suitable jointed samples for characterization. A core sample was judged suitable for study if the joint angle of intersection with the core axis was less than 45°. The selected samples were examined and described in terms of the following features: joint orientation; the type of joint infilling materials and their physical properties; and the degree of weathering along the joint surface.

Joint Wall Compressive Strength (JCS) Determination

The joint wall compressive strength of each sample was measured using a Schmidt (Model-L) rebound hammer. In order to obtain reproducible readings, one piece of each fractured pair of samples was bolted to a heavy meatal base using a constant torque of about 35 N.m. Ten rebound readings were taken with the Schmidt hammer. Generally, it was necessary to test only one wall of a joint unless there was some mineral coating along the joint surfaces. The JCS value for each joint tested was derived from the mean value of the upper 50% of the rebound hammer values. This procedure ensured automatic elimination of spurious drummy rebound values.

The unconfined compressive strength (σ_c) of the intact rock material was determined in a manner similar to the above, using intact core samples adjacent to each tested joint sample.

Rock density values were required to relate the Schmidt hammer rebound numbers to rock compressive strength by applying Miller's technique (1965). Density of samples was determined by weighing core pieces of known dimensions. In the case of extremely weathered joints, density reduction factors were applied. This procedure is described by Barton and Choubey (1977).

Joint Roughness Coefficient (JRC) Determinations

Two methods were used for determining (JRC) depending on the

orientation and roughness of a joint. These were by: (i) profiling and (ii) tilt testing.

Profiling

An impression of the joint surface was made using a profilometer. A tracing of the impression was then made on paper using a ball point pen. The joint roughness coefficient was estimated by comparing the established profile with a standard set of profiles originally developed by Barton and Choubey (1977). This procedure for estimating JRC was only used when the orientation of a joint was too steep to permit sliding without toppling, or else if the joint surfaces were sufficiently rough to prevent sliding during tilt testing.

Tilt Testing

JRC was estimated on the basis of simple tilt tests, using the following relationship:

$$JRC = \frac{\alpha_o - \phi_r}{\log_{10}\left(\frac{JCS}{\sigma_{no}}\right)} \qquad (2)$$

where α = little angle when sliding occurs (α_o = arc tan $\tau/\sigma_{no} = \phi$)

σ_{no} = effective normal stress (at angle when sliding occurs)

σ_{no} was determined in the following manner: by weighing the upper joint sample; by applying corrections to the tilt angle of sliding (if necessary); and by measuring the joint surface area.

Determination of Residual Friction Angle (ϕr)

The residual friction angle of a sample was estimated on the basis of Schmidt hammer rebound tests and tilt tests. The following empirical

relationship developed by Barton and Choubey (1977) was used for its estimation:

$$\phi_r = (\phi_b - 20°) + 20 \left[\frac{r}{R}\right] \quad (3)$$

where ϕ_b = basic friction angle estimated from residual tilt tests on dry unweathered samples (using two core samples)

r = Schmidt rebound value on weathered joint surface

R = Schmidt rebound value on unweathered surface.

DISCUSSION

A total of 139 Lac du Bonnet research area rock joint samples were investigated according to the Barton-Bandis joint model (Barton and Bakhtar, 1983). Characterized samples fell into two categories.

The first category, was composed of joint samples where all index tests required for their characterization were carried out according to the Barton-Bandis joint model. For this group, JRC was back-calculated from the other index properties of the joint samples. The range of calculated JRC values was 2.99 to 8.86. The mean and standard deviation JRC values were 6.45 and 1.40, respectively. This category had a sample population of 62. Other relevant joint sample information such as: sample depth, strike and dip angles, uniaxial compressive strength, joint wall compressive strength and the types of infilling materials contained in a joint, are provided by Jackson et al., (1985).

The second category of samples was comprised of joint core specimens which could not be subjected to all the index characterization tests required by the Barton-Bandis model. For example, most of the samples in this category could not be subjected to tilt tests, because of either insufficient joint length or poor orientation of the fracture plane. For these samples, joint roughness coefficients (JRC) were visually estimated for shear strength approximations. Seventy-seven samples treated were in this category. The estimated JRC and peak shear strength values are also summarized in Table 1. The range of calculated JRC values was 3.5 to 13.0. The mean and standard deviation values in the category were 6.0 and 1.9, respectively.

Table 1 - Summary of Rock Joint Characterization Data for Lac du Bonnet Drill Core Samples

	Unconfined* compressive strength intact rock material (σ) (MPa)	Joint wall* compressive strength (JCS) (MPa)	Joint roughness coefficient JRC		
			Calculated	Visually estimated	Combined
No. of Samples	139	139	62	77	139
Range	82-241	45-196	2.99-8.86	3.50-13.00	2.99-13.00
Mean	179.8	114.3	6.45	6.00	6.28
Std. Dev.	34.9	33.3	1.40	1.90	1.55

* Based on Schmidt hammer (Model-L) results

The basic friction angle (ϕ_b) for the Lac du Bonnet samples was estimated to be 31° by Jackson et al., (1985), and 30°, by Annor et al., (1981). These values agree very well with basic friction angle values for rocks, published by Barton and Bakhtar, (1983).

The mean and standard deviation JRC values for the Lac du Bonnet samples (Table 1) are within the range of values (6.7 to 9.7) back-calculated by Barton and Choubey (1978) for slightly weathered tectonic joints in granite. There was no correlation between the calculated JRC values and joint strike and dip orientations or sample depth for the Lac du Bonnet samples.

The predominant infilling material for the characterized joint samples was hematite (HE). The following materials were also present on joint surfaces: calcite (CA), chlorite (CL), clay (CY), biotite (BI), pyrite (PY), sericite (SR), geothite-limonite (GO), and quartz (QZ). Various researchers have

indicated that the shear strength of a rock joint is influenced significantly by the thickness, strength and fabric of the infilling materials (Barton and Bakhtar, 1983; Lama and Vutukuri, 1978; Lama, 1978 and Tulinov and Molokov, 1971). The strength and thickness of the joint infilling materials for the Lac du Bonnet samples were not determined.

CONCLUSIONS AND RECOMMENDATIONS

The Barton and Bakhtar (1983) procedures for determining the index parameters of rock joints, have been used to characterize 139 small scale fractures in drill core samples for the URL lease area, in the Lac du Bonnet batholith, Manitoba. The estimated parameters were joint wall compressive strength (JCS), joint roughness coefficient (JRC), basic and residual friction angles ($\emptyset_b$ and $\emptyset_r$, respectively) and fracture infilling material. The unconfined compressive strength of the intact rock material was also estimated for purposes of comparison. The intact rock as well as the fractured rock parameters were within the range of values listed for granites in published literature. The predominant fracture infilling material was hematite. It is expected that the information provided will contribute to the development of methodologies and models necessary for assessing the concept of underground nuclear waste disposal in plutonic rock.

Considering, however, that the mechanical behaviour of rock fractures may be size dependent, it is recommended that large scale drill core samples should be characterized to investigate size dependency.

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REFERENCES

1. Annor, A., Miles, P., Kapeller, F. and Larocque, G., "High temperature and pressure triaxial compression tests on rock samples from Pinawa and Creighton mine", Atomic Energy of Canada Limited Technical Record TR-158, (WNRE) Pinawa, Manitoba, 1981.

2. Barton, N. and Bakhtar, K. "Rock joint description and modelling for the hydrothermomechanical design of nuclear waste repositories". TerraTek contract report TRE-83-70; submitted to CANMET, Mining Research Laboratories, Energy, Mines and Resources Canada, Ottawa (1983).

3. Barton, N. and Bandis, S. "Effects of block size on the shear behaviour of jointed rock". Keynote Lecture, 23rd U.S. Symp. on Rock Mech. Berkeley California, (1982).

4. Barton, N. and Choubey. "The shear strength of rock joints in theory and practice". Rock Mech. vol. 10, p. 1-54 (1977).

5. Dormuth, W.K. "Introduction". The Geoscience Program - Proceedings of the Seventeenth Information Meeting of the Nuclear Fuel Waste Management Program (Carleton University, Ottawa), Atomic Energy of Canada Limited Technical Report TR-299 pp 7-8, 1985).

6. Jackson, R., Annor, A., Wong, A.S. and Bétournay, M. "Preliminary results of rock joint testing on URL core". Division Report ERP/MRL 85-14(TR) CANMET, Energy, Mines and Resources Canada, Ottawa, (1985).

7. Lama, R.D. "Influence of thickness to fill on shear strength of rough rock joints at low normal stresses". Grundlagen und Anwendung der Felsmechanik, Felsmechanik Kolloquium Karlsruhe 1978, Trans Techn Publications, Claussthal, Germany, 1978.

8. Lama, R.D. and Vutukuri, V.S. "Handbook on mechanical properties of rocks". Trans Tech Publications, Clausthal, Germany, 1978.

9. Simmons, G.R., Annor, A., Baumagartner, P., Lang, P.A., Larocque, G.E. and Wilkins, B.J. "The geomechanics program - A review". Proceedings of the Eighteenth Information Meeting of the Nuclear Waste Management Program (1984 General Meeting), Atomic Energy of Canada Limited, Technical Report, TR-320, pp 23-44, 1985.

10. Tulinov, R. and Molokov, L. "Role of joint filling material in shear strength of rocks". Symposium Soc. Internat. Mécanique des Roches, Nancy, 1971.